Excitation energies of two $J^\pi = 1^-$ states in ^{18}O

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The excitation energies in ^{18}O of the first two $J^\pi = 1^-$ states above the $^{14}C + \alpha$ threshold are found to be 7615.9 ± 0.7 keV and 8037.8 ± 0.7 keV. Although these energies agree within errors with the previously adopted values, they are lower by 3 keV and 1 keV, respectively. We also found $E_x(2_3^+)$, the excitation energy of the third 2^+ state, to be 5254.8 ± 0.9 keV in disagreement with the previously adopted value of 5260.4 ± 1.2 keV.

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In the calculation of the $^{14}C(\alpha,\gamma)^{18}O$ thermonuclear reaction rate, the properties of the states in ^{18}O above the $^{14}C + \alpha$ threshold are needed. There are recent measurements on the resonance strengths of the first two 1^- resonances [1,2]. However, the excitation energies of these two states are only known with an accuracy of 2–3 keV [3]. As the thermonuclear reaction rate depends approximately exponentially on the resonance energy, it is important to determine the relevant resonance energies more accurately. In addition, the β-delayed α decay of ^{18}N through these two states in ^{18}O has been used as an α-energy calibration for a recent determination of the β-delayed α spectrum from ^{16}N [4], providing an additional incentive for a remeasurement of the excitation energies. We chose to measure these excitation energies via the $^{14}C(\alpha,\gamma)^{18}O$ reaction by measuring the energy of the emitted γ rays at two angles, 90° and 0° with respect to the beam direction.

The target consisted of ~ 5 μg/cm^2 ^{14}C deposited on a 0.25 mm Ta backing. $^4He^+$ beams of 1.70–2.40 MeV were produced by the Caltech Pelletron Accelerator at intensities of 5–10 μA. The γ rays from the $^{14}C(\alpha,\gamma)^{18}O$ reaction were measured with a 35% Ge detector shielded by 5 cm Pb to reduce the γ-ray room background. The Ge detector was positioned 9.6 cm and 10.1 cm from the surface of the ^{14}C target for the 90° and 0° runs, respectively. The energy resolution was 4.5 keV for $E_\gamma \sim 5$ MeV.

We measured the yield of the resonances at $E_\alpha = 1.79$ and 2.33 MeV by varying the alpha beam energies in steps of 2 keV. By choosing beam energies close to the maximum value of the yield curve, the beam energy was corrected for the energy loss in the target. For the 1.79 MeV resonance, we used $E_\alpha = 1.806$ and 1.812 MeV for the 90° run and $E_\alpha = 1.812$ and 1.818 MeV for the 0° run. For the 2.33 MeV resonance, we used $E_\alpha = 2.348$ and 2.354 MeV for both the 90° and 0° runs. Although the available targets had undergone substantial bombardment in a previous experiment [1], causing a significant dispersion of the ^{14}C into the Ta backing, the fact that the resonances are so narrow ($\Gamma_{lab} < 3$ keV [5]) makes this unimportant.

We obtained the gamma energy scale calibration from a ^{56}Co source, and the $^{27}Al(p,\gamma)^{28}Si$ reaction at $E_p = 0.992$ MeV, a resonance that produces γ rays with many different energies associated with well-known ^{28}Si states. We used 13 γ energies from a ^{56}Co source and the background ^{40}K and ^{208}Tl peaks, and 14 energies from the $^{27}Al(p,\gamma)^{28}Si$ reaction. These calibration points range from 847 keV to 10 762 keV and provide a very satisfactory calibration curve for our measurements. For the $^{27}Al(p,\gamma)$ measurements, we used only the primary gammas from the resonance state at $E_x = 12\,541$ keV to lower excitation states in ^{28}Si, employing the values from Ref. [6], because cascade γ energies may be affected by Doppler shifts or broadening depending on the lifetimes of the intermediate states involved. Immediately after the $^{14}C(\alpha,\gamma)^{18}O$ reaction measurements at each angle, we ran the $^{27}Al(p,\gamma)^{28}Si$ reaction without changing the detector and electronics setup. We obtained ^{56}Co source spectra frequently, for the gamma-energy calibration curves and to check for any small gain shifts during the experiment; no such gain shifts were found. Corrections for recoil energy, Doppler shift, and the effective detector angle at 0° have been applied to all of our data.

The 7.62 MeV state. At $\theta = 90°$, the deexcitation γ-ray yield from the 7.62 MeV state is primarily to the ground, 1982, 4456, and 5336 keV states, and, at $\theta = 0°$, to the 1982 and 4456 keV states. All of these excitation energies are known to better than 0.6 keV. From the γ-ray peaks corresponding to these transitions, we have independent measurements of the excitation energy of the 7.62 MeV state, with the results shown in Table I. The errors in the fourth column arise from the statistical errors in peak positions and from the quality of the calibration curves used to convert peak positions to energies. The errors in the fifth column are the sums in quadrature of the errors due to the peak positions and the errors due to the uncertainties in the final state excitation energies. In addition to the statistical errors, we assigned a systematic error arising from the accuracy with which the detector can be positioned. The estimated 1° uncertainty for the 90° position introduces an uncertainty of 0.7 keV in the final excitation energy. Similarly, the estimated 1° error in the the 0° position introduces an uncertainty of only 0.1 keV. Our measured excitation energy for the 7.62 MeV state is $7615.9 \pm 0.1 \pm 0.7$ keV, the first error being the weighted statistical error and the second one the systematic error.

From the "internal" calibrations based on the accurate

TABLE I. Excitation energy of the 7.62 MeV state in ^{18}O.

θ_{lab} (deg)	E_α[a] (keV)	E_{xf}[b] (keV)	E_γ[c] (keV)	E_{xi} (keV) Present	Ref. [3]
90	1806	5336.4 ± 0.6	2279.53 ± 0.22	7616.14 ± 0.64	
	1806	4455.54 ± 0.10	3159.69 ± 0.46	7615.60 ± 0.47	
	1806	1982.07 ± 0.09	5632.81 ± 0.21	7615.96 ± 0.23	
	1806	0.0	7614.09 ± 0.41	7616.00 ± 0.41	
	1812	5336.4 ± 0.6	2280.03 ± 0.13	7616.64 ± 0.61	
	1812	4455.54 ± 0.10	3159.72 ± 0.22	7615.63 ± 0.24	
	1812	1982.07 ± 0.09	5632.86 ± 0.11	7616.02 ± 0.14	
	1812	0.0	7614.41 ± 0.22	7616.32 ± 0.22	
0	1812	4455.54 ± 0.10	3181.31 ± 0.08	7615.67 ± 0.13	
	1812	1982.07 ± 0.09	5671.05 ± 0.06	7615.77 ± 0.11	
	1818	4455.54 ± 0.10	3181.43 ± 0.10	7615.78 ± 0.14	
	1818	1982.07 ± 0.09	5671.32 ± 0.10	7616.03 ± 0.13	
				7615.9 ± 0.1 ± 0.7[d]	7619 ± 3

[a]Incident α energy, ±2 keV from magnetic analyzer calibration.
[b]From Ref. [3].
[c]Gamma energies corresponding to the transition from E_{xi} to E_{xf} obtained from our calibration curves.
[d]Of the two errors given, the first is the weighted statistical error and the second is the systematic error as explained in text.

energies given in Ref. [3] for E_x = 1.982 and 4.456 MeV (also including 5.336 MeV for the 90° case) in ^{18}O, and the background peaks from ^{40}K and ^{208}Tl, the excitation energy was obtained to be 7615.9±0.4 keV (not including systematic uncertainty from angle), in good agreement with that extracted from the other energy calibrations and listed in Table I.

The 8.04 MeV state. At θ = 90°, the deexcitation γ-ray yield from the 8.04 MeV state is primarily to the ground, 1982, 3634, and 5260 keV states, and, at $\theta = 0°$, to the 1982 and 5260 keV states. All of these excitation energies are known to better than 0.11 keV except that for the 5.26 MeV state as shown in the third column in Table II. Our measured excitation energy of the higher 1^- state is 8037.8 ± 0.1 ± 0.7 keV.

We consistently obtained much higher excitation en-

TABLE II. Excitation energy of the 8.04 MeV state in ^{18}O.

θ_{lab} (deg)	E_α[a] (keV)	E_{xf}[b] (keV)	E_γ[c] (keV)	E_{xi} (keV) Present	Ref. [3]
90	2348	5260.4±1.2	2782.17 ± 0.25	8042.88 ± 1.22	
		(5255.0 ± 0.7)[d]		(8037.8)	
	2348	3633.76 ± 0.11	4403.03 ± 0.19	8037.50 ± 0.22	
	2348	1982.07 ± 0.09	6054.35 ± 0.11	8037.70 ± 0.14	
	2348	0.0	8035.49 ± 0.27	8037.66 ± 0.27	
	2354	5260.4 ± 1.2	2782.50 ± 0.39	8043.21 ± 1.26	
		(5255.0 ± 0.8)[d]		(8037.8)	
	2354	3633.76 ± 0.11	4403.46 ± 0.23	8037.93 ± 0.26	
	2354	1982.07 ± 0.09	6054.79 ± 0.14	8038.14 ± 0.17	
	2354	0.0	8035.76 ± 0.37	8037.93 ± 0.37	
0	2348	5260.4 ± 1.2	2804.48 ± 0.19	8043.46 ± 1.21	
		(5254.7 ± 0.7)[d]		(8037.8)	
	2348	1982.07 ± 0.09	6101.28 ± 0.06	8037.42 ± 0.11	
	2354	5260.4 ± 1.2	2804.83 ± 0.22	8043.80 ± 1.22	
		(5254.4 ± 0.7)[d]		(8037.8)	
	2354	1982.07 ± 0.09	6101.65 ± 0.06	8037.78 ± 0.11	
				8037.8 ± 0.1 ± 0.7[e]	8039 ± 2

[a]Incident α energy, ±2 keV from magnetic analyzer calibration.
[b]From Ref. [3].
[c]Gamma energies corresponding to the transition from E_{xi} to E_{xf} obtained from our calibration curves.
[d]The transition from E_{xi} = 8037.8 keV to this state.
[e]Of the two errors given, the first is the weighted statistical error and the second is the systematic error as explained in text.

ergies for the 8.04 MeV state from the transition to the 5.26 MeV state than from the other three transitions. This indicates strongly that the previously reported excitation energy for the 5.26 MeV state must be too high. The values in the parentheses in the third column are the indicated excitation energies of this state obtained by using our new excitation energy for the 8.04 state. The new weighted average for the excitation energy is 5254.8 ± 0.9 keV.

We have determined the excitation energies of three ^{18}O states with much higher accuracy than previously available: 5254.8 ± 0.9, 7615.9 ± 0.7, and 8037.8 ± 0.7 keV. Our new excitation energy for the 2_3^+ state is in disagreement with the previous value. Our excitation energy values for the two 1^- states are lower than previously quoted, but agree with the previous values within the assigned errors.

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